3 ECONOMIC ANALYSIS

This section presents cost estimates for using the E-Beam technology to treat groundwater contaminated with MtBE. Cost data were obtained during the demonstration at the NBVC, during the previous demonstration at the Savannah River Site, and from Haley and Aldrich. For comparability, these costs have been placed in the 12 categories applicable to typical cleanup activities at Superfund and RCRA sites (Evans 1990). Costs are considered to be order-of-magnitude estimates with an expected accuracy of from 50% above to 30% below actual costs. This section describes the applications selected for economic analysis, summarizes the major issues involved and assumptions made in performing the economic analysis, lists the costs associated with using the E-Beam technology in the selected applications, and then develops at a cost per unit volume of water treated for each application.

Two applications were selected for the economic analysis. The first application assumes the scenario of the demonstration at NBVC within the MTBE Source Zone, including the contaminant levels in the groundwater at that location and the treatment goals that were developed for the demonstration. This scenario is essentially a remedial application, since the levels of MTBE in the influent were much higher (about 2,000 μg/L) than would likely be treated for subsequent use as a drinking water source.

The second application is for a larger-scale utilization as part of a drinking water treatment plant, in which the E-beam system would be used to treat the groundwater to remove MtBE. The scale selected for this application is 10 MGD, which is intended to simulate a small drinking water treatment plant. In this scenario, a lower influent concentration of MTBE (200 μg/L) was assumed and the California secondary MCL for MTBE (5 μg/L) was assumed to be the applicable regulatory criterion for the treated water.

3.1 GENERAL ISSUES AND ASSUMPTIONS

Prior to presenting the cost estimates for each of the selected applications, it is important to describe how costs associated with an E-beam application can vary based on numerous factors, such as the type and scale of the application, contaminant types and levels, regulatory criteria, and site-specific factors. A discussion of some of the primary factors that affect the cost of an E-beam system is provided in Sections 3.1.1 through 3.1.4 below. A discussion of general assumptions utilized in the subsequent cost analysis is then provided in Section 3.1.5.

3.1.1 Type and Scale of Application

The E-beam system can be used both as a drinking water treatment technology and as a remedial technology. In a drinking water treatment application, the E-beam technology would typically be applied to treat organic contaminants, such as MtBE, that are not typically removed by conventional water treatment technologies. In a remedial application, the E-beam technology may be used to clean up contaminated groundwater at a RCRA corrective action or Superfund site. Remedial applications will typically involve much higher costs per unit volume of water treated for several reasons:

- Site preparation costs may be significant as utilities and other infrastructure may not be immediately available at the site.
- Remedial applications are typically temporary installations and will therefore involve substantial mobilization and demobilization costs.
- Installation of well fields may be needed to extract the contaminated groundwater.
- Treatment volumes and the time period required to achieve site closure may not be certain.
- Permitting and other regulatory-driven costs may be higher due to the complex nature of site cleanups.

The scale of the application is a primary factor that affects the unit cost per volume of water treated for a technologically sophisticated system such as the E-beam. Larger scale applications incorporate substantial equipment cost savings on a cost per unit volume of water treated because the E-beam generator, equipment housings, control systems, and appurtenances are only slightly more expensive for larger E-beam systems. Labor costs are also proportionately lower due to the use of full-time, dedicated staff for equipment operations and maintenance.

3.1.2 Contaminant Types and Levels

As shown in the demonstration at NBVC and in previous demonstrations, some contaminants are relatively easy to destroy even at low E-beam doses, whereas other contaminants (such as tBA) are much more difficult to destroy, even at high doses. Further, the required E-beam dose increases with increasing contaminant concentrations in the influent water. Higher E-beam doses require larger scale E-beam generators and proportionately higher energy consumption.

3.1.3 Regulatory Criteria

Regulatory criteria for the treated water affect the same variables as contaminant types and levels. More stringent regulatory criteria for the treated water can greatly increase the dose required and the corresponding size of the E-beam system as well as the associated energy costs. Regulatory criteria also affect permitting costs and effluent monitoring (analytical) costs.

3.1.4 Site-specific Features

Site-specific features can affect the costs of using the E-Beam treatment system, particularly in remedial applications. Site features affecting costs include groundwater recharge rates, groundwater chemistry, site accessibility, availability of utilities, and geographic location. Groundwater recharge rates affect the time required for cleanup. Site accessibility, availability of utilities, and site location and size all affect site preparation costs.

3.1.5 General Assumptions

Certain assumptions were made to simplify the cost estimating for situations that actually would require complex engineering and financial considerations. The following general assumptions were made for the cost analysis that is presented subsequently:

- Costs are rounded to the nearest $100 and to the nearest $0.01 per 1,000 gallons.
- Equipment costs for the E-beam system are for the entire system, including control systems and appurtenances, and are as provided by Haley and Aldrich.
- Equipment costs are amortized linearly without interest over the period of projected operation and up to the projected useful life of these systems (20 years); no salvage value is assumed.
- An E-beam system will provide a dose of 1,000 krads to a 1.0-gpm stream at a 100 kW power input; this assumes an electrical energy input to absorbed radiation conversion efficiency of about 63%.
- The E-Beam equipment will be properly maintained and will continue to operate at the same efficiency for the assumed useful life of the equipment or for the duration of the groundwater treatment project, if less than 20 years.
- Operational labor costs $40 per hour, fully burdened (including office space, office equipment and supplies, and fringe benefits).
- Annual equipment maintenance costs are about 5% of the capital equipment costs, based on estimates provided by Haley and Aldrich.
- Electrical power costs $0.10 per kW-hr delivered to the site.
- The costs presented in the analysis below will need to be adjusted for applications where other assumptions are appropriate and for the site-specific contaminants and treatment goals of these applications.

3.2 REMEDIAL APPLICATION AT 10 GPM

The equipment and operational assumptions for the remedial application are listed below:

- A 21-kW E-beam system is used, similar to the existing trailer-mounted system, and is operated 24 hours per day, 7 days per week, 52 weeks per year for 10 years to clean up the contaminated groundwater.
- The treatment system operates at the full power of 21 kW (a voltage of 500 kV and a beam current of 42 mA).
- The groundwater to be treated is identical to that observed during the demonstration within the Source Zone at NBVC; thus, a dose of 2,000 krads is needed to destroy tBA (the rate limiting contaminant) to below the treatment goal of 12 µg/L in the effluent.
- The E-beam system is operated at a flow of 10 gpm, which is the maximum flow to achieve a dose of 2,000 krad at full power.

- The treatment system operates automatically without the constant attention of an operator and will shut down in the event of system malfunction.
- Modular components consisting of the equipment needed to meet treatment goals are mobilized to the site and assembled by Haley and Aldrich.
- The E-Beam system is mobilized to the site from within 1,000 miles of the site.
- Haley and Aldrich provides initial operator training and startup assistance to assure that the E-beam system functions properly.
- Air emissions monitoring is not necessary.
- A treatability study will be conducted by Haley and Aldrich to confirm dose requirements and other operational variables.

Table 3-1 summarizes the estimated costs for this application, and the sections below detail the basis for the cost calculations associated with each of the following 12 cost categories: (1) site preparation, (2) permitting and regulatory, (3) mobilization and startup, (4) equipment, (5) labor, (6) supplies, (7) utilities, (8) effluent treatment and disposal, (9) residual waste shipping and handling, (10) analytical services, (11) equipment maintenance, and (12) site demobilization.

3.2.1 Site Preparation Costs

Site preparation costs include administrative, treatment area preparation, treatability study, and system design costs. For this application, site preparation administrative costs, such as costs for legal searches, access rights, and site planning activities, are estimated to be $35,000.

Table 3-1. Economic Analysis of the Remedial Application at 10 gpm.

		21-kW E-Beam System (10 gallons per minute)		
			total	
		itemized (costs)	cost	cost/1,000 gallons
Site Preparation			$ 175,600	$ 3.34
	Administrative	$ 35,000		
	Treatment Area Preparation	$ 107,600		
	Treatability Study and System Design	$ 33,000		
Permitting and Regulatory			$ 5,000	$ 0.10
Mobilization and Startup			$ 20,000	$ 0.38
	Transportation	$ 10,000		
	Assembly and Shakedown	$ 10,000		
Equipment			$ 842,000	$ 16.02
Labor			$ 20,800/yr	$ 3.95
Supplies			$ 1,700	$ 0.32
	Disposable Personal Protective Equipment	$ 600		
	Fiber Drums	$ 100		
	Sampling Supplies	$ 1,000		
Utilities			$ 35,800/yr	$ 6.81
Effluent Treatment and Disposal			NA	$ -
Residual Waste Shipping and Handling			$ 600/yr	$ 0.11
Analytical Services			$ 7,200/yr	$ 1.37
Equipment Maintenance			$ 42,200/yr	$ 7.87
Site Demobilization			$ 15,000	$ 0.28
		Total Cost ($/1000 gallons)		$ 40.55

Treatment area preparation includes constructing a shelter building and installing pumps, valves, and piping from the extraction wells to the shelter building. The shelter building needs to be constructed before mobilization of the E-Beam system. A 400-square-foot building is required for the 21-kW system. Haley and Aldrich will provide the shelter building design specifications. Construction costs are estimated to be about $110 per square foot, which covers installation of radiation shielding materials. A natural gas heating and cooling unit and ductwork costs about $20,000 installed. The total shelter building construction costs for the 21-kW system are estimated to be $64,000.

This analysis assumes that four extraction wells are installed on site and that they are located 200 feet from the shelter building. Four 5-gpm, 0.5-horsepower, variable-speed pumps are required to pump contaminated groundwater from wells at a total flow rate of 10 gpm. The total well and pump costs, including all electrical equipment and installation, are $11,600. Piping and valve connection costs are about $40 per foot, which covers underground installation. Therefore, the total piping costs are $32,000. The total treatment area preparation costs are estimated to be $107,600.

It is assumed that Haley and Aldrich will transport its mobile system to the site to perform a treatability study and to test the equipment under site conditions. Six to eight samples will be collected from the influent and effluent and will be analyzed off site for VOCs. Haley and Aldrich estimates the treatability study cost to be $18,000, including labor and equipment costs. The treatability study includes determining appropriate E-Beam dose to achieve the treatment goals and designing the configuration. The system design is estimated to cost $15,000. Total site preparation costs are therefore estimated to be $175,600.

3.2.2 Permitting and Regulatory Costs

Permitting and regulatory costs depend on whether treatment is performed at a Superfund or a RCRA corrective action site and on how treated effluent and any solid wastes are disposed of. Superfund site remedial actions must be consistent with all applicable environmental laws, ordinances, regulations, and statutes, including federal, state, and local standards and criteria. Remediation at RCRA corrective action sites requires additional monitoring and record keeping, which can increase the base regulatory costs. In general, applicable or relevant and appropriate requirements (ARARs) must be determined on a site-specific basis. Permitting and regulatory costs in this analysis include permit fees for discharging treated water to a surface water body. The cost of this permit would be based on regulatory agency requirements and treatment goals for a particular site. The discharge permit is estimated to cost $5,000.

3.2.3 Mobilization and Startup Costs

Mobilization and startup costs include the costs of transporting the E-Beam system to the site, assembling the E-Beam system, and performing the initial shakedown of the treatment system. Haley and Aldrich provides trained personnel to assemble and conduct preliminary tests on the E-Beam system. Haley and Aldrich personnel are trained in hazardous waste site health and safety procedures, so health and safety training costs are not included as a direct startup cost. Initial operator training is needed to ensure safe, economical, and efficient operation of the system. Haley and Aldrich provides initial operator training to its clients as part of providing the E-Beam equipment. Transportation costs are site-specific and vary depending on the location of the site in relation to the equipment. For this analysis, the E-Beam equipment is assumed to be transported 1,000 miles. Haley and Aldrich retains the services of a cartage company to transport all E-Beam treatment system equipment. Mobilization costs are about $10 per mile for a total cost of $10,000. The costs of highway permits for overweight vehicles are included in this total cost. Assembly costs include the costs of unloading equipment from the trailers, assembling the E-Beam system, hooking up extraction well piping, and hooking up electrical lines. A two-person crew will work three 8-hour days to unload and assemble the system and perform the initial shakedown. The total startup costs are about $10,000, including labor and hookup costs. Total mobilization and startup costs are therefore estimated to be $20,000.

3.2.4 Equipment Costs

Haley and Aldrich estimates that the capital equipment cost is $842,000 for a 21-kW system.

3.2.5 Labor Costs

Once the system is functioning, it is assumed to operate continuously at the designed flow rate except during routine maintenance. One operator trained by Haley and Aldrich performs routine equipment monitoring and sampling activities. Under normal operating conditions, an operator is required to monitor the system about once each week. This analysis assumes that the work is conducted by a full-time employee of the site owner and is assigned to be the primary operator to perform system monitoring and sampling duties. Further, it is assumed that a second person, also employed by the site owner, will be trained to act as a backup to the primary operator. Based on observations made at the NBVC demonstration, it is estimated that operation of the system requires about 10 hours per week of a primary operator’s time. Assuming that the primary operator’s burdened labor rate is $40 per hour, the total annual labor cost is estimated to be $20,800.

3.2.6 Supply Costs

No chemicals or treatment additives are expected to be needed to treat the groundwater using the E-Beam technology. Therefore, no direct supply costs are expected to be incurred. Supplies that will be needed as part of the overall groundwater remediation project include Level D, disposable personal protective equipment (PPE), PPE disposal drums, and sampling and field analytical supplies. Disposable PPE typically consists of latex inner gloves, nitrile outer gloves, radiation badges, and safety glasses. This PPE is needed during periodic sampling activities. Disposable PPE for is assumed to cost about $600 per year for the primary operator. Used PPE is assumed to be hazardous and needs to be disposed of in 24-gallon, fiber drums. One drum is assumed to be filled every 2 months, and each drum costs about $12. The total annual drum costs rounded to the nearest $100 are about $100.

Sampling supplies consist of sample bottles and containers, ice, labels, shipping containers, and laboratory forms for off-site analyses. For routine monitoring, laboratory glassware is also needed. The numbers and types of sampling supplies needed are based on the analyses to be performed. Costs for laboratory analyses are presented in Section 3.2.10. The sampling supply costs are estimated to be $1,000 per year. Total annual supply costs are estimated to be $1,700.

3.2.7 Utility Costs

Electricity is the only utility used by the E-Beam system. Electricity is used to run the E-Beam treatment system, pumps, blower, and air chiller. This analysis assumes that electrical power lines are available at the site. Electricity costs can vary considerably depending on the geographical location of the site and local utility rates. Also, the consumption of electricity varies depending on the E-Beam system used, the total number of pumps and other electrical equipment operating, and the use of the air chiller.

This analysis assumes a constant rate of electricity consumption based on the electrical requirements of the E-Beam treatment system (21-kW). The pumps, blower, and air chiller are assumed to draw an additional 20 kW. Therefore, the 21-kW unit operating for 1 hour draws about 41 kW hours (kWh) of electricity. The total annual electrical energy consumption is estimated to be about 358,176 kWh. Electricity is assumed to cost $0.10 per kWh, including demand and usage charges. The total annual electricity costs are therefore estimated to be about $35,800.

3.2.8 Effluent Treatment and Disposal Costs

Depending on the treatment goals for a site, additional effluent treatment may be required, and thus additional treatment or disposal costs may be incurred. Because of the uncertainty associated with additional treatment or disposal costs, this analysis does not include effluent treatment or disposal costs. The E-Beam system does not produce air emissions because the water delivery and cooling air systems are enclosed. As a result, no cost for air emissions treatment is incurred. It is assumed that the primary operator routinely conducts effluent monitoring. The effluent can be discharged directly to a nearby surface water body, provided that appropriate permits have been obtained (see Section 3.2.2).

3.2.9 Residual Waste Shipping and Handling Costs

The only residuals produced during E-Beam system operation are fiber drums containing used PPE and waste sampling and field analytical supplies, all of which are typically associated with a groundwater project. This waste is assumed to be non-hazardous with associated disposal at a non-hazardous waste landfill. This analysis assumes that about six drums of waste are disposed of annually. The cost of handling and transporting the drums and disposing of them at a non-hazardous waste disposal facility is about $100 per drum. The total drum disposal costs are therefore about $600 per year.

Condensate is generated from the air chiller. This condensate can be treated by the E-Beam system, but such treatment may require additional permits from regulatory authorities. Because of the uncertainty associated with the need for additional permits, the costs for such additional permits were not included in this analysis.

3.2.10 Analytical Services Costs

Required sampling frequencies are highly site specific and are based on treatment goals and contaminant concentrations. Analytical costs associated with a groundwater treatment project include the costs of laboratory analyses, data reduction, and QA/QC. This analysis assumes that one sample of untreated water, one sample of treated water, and associated QC samples (trip blanks, field duplicates, and matrix spike/matrix spike duplicates) will be analyzed for VOCs every month. Monthly analytical costs are estimated at $600. The total annual analytical costs are therefore estimated to be $7,200.

3.2.11 Equipment Maintenance Costs

Haley and Aldrich estimates that annual equipment maintenance costs are about 5% of the capital equipment costs. Therefore, the total annual equipment maintenance costs are about $42,200 for the 21-kW system.

3.2.12 Site Demobilization Costs

Site demobilization includes treatment system shutdown, disassembly, and decontamination; site cleanup and restoration; utility disconnection; and transportation of the E-Beam equipment off site. A two-person crew will work about five 8-hour days to disassemble and load the system. This analysis assumes that the equipment will be transported 1,000 miles either for storage or to the next job site. Haley and Aldrich estimates that the total cost of demobilization is about $15,000. This total includes all labor, material, and transportation costs.

3.3 DRINKING WATER TREATMENT APPLICATION AT 10 MGD

The equipment and operating parameter assumptions for the larger-scale drinking water treatment application are based on a recent treatability study performed by Haley and Aldrich using groundwater contaminated with MtBE from Santa Monica, California, as reported by Haley and Aldrich (Nickelsen, 2002). Approximately 1,800 gallons of groundwater from Santa Monica was transported in a clean tanker truck and treated in the 21-kW trailer-mounted E-beam system that was still on site at NVBC. Due to low native concentrations of MtBE in the Santa Monica groundwater, the water was spiked with 200 μg/L MtBE in one experiment intended to simulate a drinking water supply recently contaminated with MtBE. In this experiment, a dose of 167 krads (the lowest dose tested) was sufficient to remove MtBE to well below the treatment goal of 5 μg/L without increasing the concentration of TBA to above 12 μg/L. This scenario was assumed as the basis for the economic analysis below.

The equipment and operational assumptions for the drinking water treatment application are listed below:

- The treatment system processes 10 MGD and is operated 24 hours per day, 7 days per week, 52 weeks per year for 20 years (the useful life of the equipment).
- A dose of 167 krads is required, which can be provided using with twelve 100-kW E-beam systems for a flow of 10 MGD.
- Modular components consisting of the equipment needed to meet treatment goals are mobilized to the site and assembled by Haley and Aldrich.
- Haley and Aldrich provides initial operator training and startup assistance to ensure that the E-beam system functions properly.

- A treatability study is conducted by Haley and Aldrich to confirm dose requirements and other operational variables.
- Air emissions monitoring is not necessary.

Table 3-2 summarizes the estimated costs for this application. The assumptions associated with the cost analysis, which emphasizes the differences from the remedial application, are summarized below:

- The capital equipment cost of each 100-kW E-beam system is $1.5 million, fully installed.
- The following site preparation costs are estimated as percentages of the capital equipment cost: administration, 1%; site preparation, 3%; and system design (including the treatability study), 6%.
- Two full-time operators are required to ensure proper functioning of the treatment system.
- Permitting and regulatory costs are $50,000.
- Shakedown and start-up costs are $700,000.
- Supply and residual waste handling costs are eight times that of the remedial scenario (proportional to operating labor hours).
- Electrical energy demand for the treatment system includes 1,200 kW for the beams themselves and 600 kW for the associated blowers, pumps, and appurtenances.
- Laboratory analysis support requirements assume that one sample of untreated water, one sample of treated water, and associated QC samples will be analyzed for VOCs every day at a cost of $600 per day.
- Equipment transportation costs are included in the installed equipment cost item and there is no demobilization cost.

Table 3-2. Economic Analysis of the Drinking Water Treatment Application at 10 MGD.

		1200-kW E-Beam System (10 MGD)		
			total	
		itemized (costs)	cost	cost/1,000 gallons
Site Preparation			$ 1,720,000	$ 0.02
	Administrative	$ 180,000		
	Treatment Area Preparation	$ 540,000		
	Treatability Study and System Design	$ 1,080,000		
Permitting and Regulatory			$ 50,000	$ 0.00
Mobilization and Startup			$ 700,000	$ 0.01
	Transportation	NA		
	Shakedown and Startup	$ 700,000		
Equipment			$ 18,000,000	$ 0.25
Labor			$ 163,200/yr	$ 0.04
Supplies			$ 13,600	$ 0.00
	Disposable Personal Protective Equipment	$ 4,800		
	Fiber Drums	$ 800		
	Sampling Supplies	$ 8,000		
Utilities			$ 1,576,800/yr	$ 0.43
Effluent Treatment and Disposal			NA	$ -
Residual Waste Shipping and Handling			$ 4,800/yr	$ 0.00
Analytical Services			$ 219,000/yr	$ 0.06
Equipment Maintenance			$ 900,000/yr	$ 0.25
Site Demobilization		NA		
		Total Cost ($/1000 gallons)		$ 1.06

NA = Not applicable.